

**BBC**

# Research Department Report

September 1987

## **BAND II VHF ANTENNA FOR HOME CONSTRUCTION**

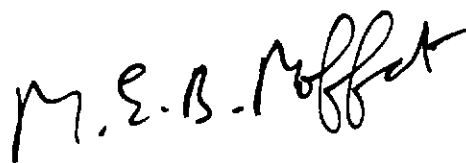
S. Wakeling, B.Sc.



**BAND II VHF ANTENNA FOR HOME CONSTRUCTION****S. Wakeling, B.Sc.****Summary**

*A wideband Band II Yagi antenna, suitable for home construction, has been designed using computer techniques. The antenna is intended for use as a domestic receiving antenna for VHF/FM sound broadcasting at frequencies in the range 88 to 108 MHz. Scale-model antennas were constructed and measured to verify the performance predicted by the computer. Finally, a full-scale Yagi antenna was constructed and its radiation patterns measured. The measurements on the new antenna and on some commercially made antennas, which all had performances inferior to the new antenna, throw doubt upon the practicability or usefulness of the directivity characteristic in CCIR Recommendation 599.*

Issued under the Authority of



Head of Research Department

**Research Department, Engineering Division,  
BRITISH BROADCASTING CORPORATION**

This Report may not be reproduced in any form  
without the written permission of the  
British Broadcasting Corporation

It uses SI units in accordance with B.S. document  
PD 5686

#### UNIVERSAL DECIMAL CLASSIFICATION

It is intended that the UDC reference (see Summary page, top right) will, from 1988 onwards, be omitted from BBC Research Reports. The classification is not generally used elsewhere within the BBC. Should, however, the lack of this reference be of particular concern to you would you kindly write to:

The Research Executive,  
BBC Research Department, Kingswood Warren,  
Tadworth, Surrey, KT20 6NP, England.

# **BAND II VHF ANTENNA FOR HOME CONSTRUCTION**

**S. Wakeling, B.Sc.**

<i>Section</i>	<i>Page</i>
<b>1. Introduction</b>	<b>1</b>
<b>2. Antenna Requirements</b>	<b>1</b>
<b>3. Computer Program</b>	<b>1</b>
<b>4. Results of Computations</b>	<b>2</b>
4.1 Reduced element design	2
<b>5. Scale Model Yagi Antennas</b>	<b>2</b>
<b>6. Full-Size Antenna Results</b>	<b>3</b>
6.1 Performance of the original Yagi antenna	3
6.2 Performance of the new wideband design	3
6.3 Construction of the proposed design	6
<b>7. CCIR Recommended Patterns for Domestic VHF Receiving Antennas</b>	<b>6</b>
<b>8. Discussion</b>	<b>7</b>
<b>9. Conclusions</b>	<b>8</b>
<b>10. References</b>	<b>8</b>
<b>Appendix 1 BBC Engineering Information Department. Information Sheet No. 1104(4). VHF Radio Receiving Aerials</b>	<b>(facing p.8)</b>
<b>Appendix 2 CCIR Recommendation 599</b>	<b>11</b>
<b>Appendix 3 Scale-model Yagi Antennas</b>	<b>12</b>
A3.1 Yagi antenna with a single dipole driven element	12
A3.2 Yagi antenna design with a folded dipole	16
A3.3 Sensitivity to constructional errors	18

© BBC 2006. All rights reserved. Except as provided below, no part of this document may be reproduced in any material form (including photocopying or storing it in any medium by electronic means) without the prior written permission of BBC Research & Development except in accordance with the provisions of the (UK) Copyright, Designs and Patents Act 1988.

The BBC grants permission to individuals and organisations to make copies of the entire document (including this copyright notice) for their own internal use. No copies of this document may be published, distributed or made available to third parties whether by paper, electronic or other means without the BBC's prior written permission. Where necessary, third parties should be directed to the relevant page on BBC's website at <http://www.bbc.co.uk/rd/pubs/> for a copy of this document.

# BAND II VHF ANTENNA FOR HOME CONSTRUCTION

S. Wakeling, B.Sc.

## 1. INTRODUCTION

The number of VHF radio programmes broadcast in the UK is likely to increase in the future. At present, the lower and mid-band frequencies of the *Band II spectrum are almost fully occupied by the existing services*. In accordance with the 1984 VHF Regional Administrative Radio Conference, new transmissions will increasingly be fitted into the upper frequency range of Band II, between 98 and 108 MHz, as these frequencies become clear of existing mobile services<sup>1</sup>.

Up to 1979, the BBC's Engineering Information Department recommended a VHF antenna design for home construction which covers the bandwidth 88 to 98 MHz (Appendix 1 contains the design information). It is a Yagi antenna which has a limited bandwidth for satisfactory radiation patterns and input impedance. The deterioration in performance is usually more rapid at frequencies above the design frequency rather than below it, so the present Yagi design cannot be expected to cover the proposed bandwidth. A new Yagi antenna has been designed, with emphasis given to its operation over a wide (20%) bandwidth, 88 to 108 MHz.

This Report describes the measurement of the existing recommended Yagi antenna and the design and testing of a new antenna. A computer program was used to predict the patterns for a number of Yagi antenna designs. Scale-model measurements were then made to verify the accuracy of the computed antenna performance. A full-size version was constructed and a matching network added to improve the input impedance. The performance of the final design has been compared with the original Yagi antenna and is recommended as a replacement for it. The BBC's Engineering Information Department will shortly issue this new design for home construction.

## 2. ANTENNA REQUIREMENTS

The new antenna design should comply with the CCIR directivity characteristic for domestic receiving antennas in Band II (Appendix 2) which is used for planning. It must cover the new band of 88 to 108 MHz with a similar performance to the original Yagi antenna. However, it would be beneficial to be able to increase the front-to-back ratio to 20 dB which would reduce co-channel interference from transmitters on substantially different azimuths.

Yagi antennas are inherently narrow-band devices and the mid-band gain has to be sacrificed to provide a reasonable performance over the required bandwidth. The input impedance of the antenna should be 75  $\Omega$  for domestic use.

Its ease of construction is also important. For this reason a simple dipole is used for the driven element, although a folded dipole was used in one experiment. Also, the design must not be very sensitive to small errors in the element lengths and positions. The proposed constructional tolerances are  $\pm 10$  mm.

Many VHF services in the UK are now transmitted with mixed polarisation. This means that more care needs to be taken of its cross-polar discrimination and conductors which are not in the plane of the antenna will affect its performance. This has to be taken into account when the antenna is mounted and the feed connected.

## 3. COMPUTER PROGRAM

A computer program was written previously<sup>2</sup> to calculate the performance of end-fire arrays. It computes the radiation patterns, element currents and input impedances given the element length and thickness and their relative spacing. The method used in the program is that of solving the matrix equation

$$[V_A] = [Z_A] [I_A]$$

where V and I are the voltages and currents in the elements and Z is the matrix of the self and mutual impedances. The E-plane and H-plane radiation patterns are then calculated from the currents in the elements.

A wideband Yagi antenna can be designed using an iterative procedure. The start point is a known narrowband antenna design. The length and spacing of the elements are altered by small amounts, usually in 10 mm steps, and the computer program calculates the horizontal radiation patterns (h.r.ps). This is done at several different frequencies to establish a band of frequencies over which the performance of the antenna is acceptable. The length and spacing of the elements are then altered again until the design gives acceptable patterns over the required frequency range of 88 to 108 MHz.

#### 4. RESULTS OF COMPUTATIONS

The number of permutations of input parameters is large and it is expensive and time consuming to make a really comprehensive investigation of all combinations of parameters. The priority is to design an antenna to cover the required bandwidth. It is suggested<sup>3</sup> that if the directors are made shorter than the optimum gain length of just less than  $\lambda/2$  and the reflector is made longer, the bandwidth can be widened at the expense of the peak gain. Also, if the directors are longer than  $\lambda/2$  at the highest frequency at which the antenna is to operate, it will fire backwards. That is, the backward lobe will have a larger magnitude than the forward lobe. (This happens to the original antenna at 100 MHz). So the front director must be shorter than  $\lambda/2$  at 108 MHz.

The final design is a compromise which covers the required bandwidth with the maximum possible front-to-back ratio and gain.

The dimensions of the antenna giving the optimum compromise between bandwidth and gain is shown in Fig. 1 with the dimensions in wavelengths in Table 1. The wavelength,  $\lambda$ , is taken at mid-band.

Table 1 - Dimensions of Proposed Design

	Dimension	Length in wavelengths
Length	a	$0.55\lambda$
	b	$0.5\lambda$
	c	$0.42\lambda$
	d	$0.375\lambda$
Spacing	e	$0.25\lambda$
	f	$0.075\lambda$
	g	$0.162\lambda$
Diameter	h	$0.004\lambda$

This antenna operates over the required bandwidth with a predicted front-to-back ratio of 16 to 17 dB and a gain between 4.5 and 5.5 dB. The computer predicts that the input impedance will be near  $50 \Omega$  just below the centre of the frequency band but will become capacitive at the low frequency end and inductive at the high frequency end. The predicted performance is compared with the measured results in Appendix 3.

#### 4.1 Reduced element design

The BBC's original antenna design can be constructed with 4, 3 or even 2 elements.

Computer predictions of the performance of the proposed wideband Yagi antenna show that the front-to-back ratio is reduced and the gain drops for a design with a reduced number of elements. Fig. 2 shows the h.r.p.s for 4, 3 and 2 element Yagi antennas, at 98 MHz. The results were similar at other frequencies in the band.

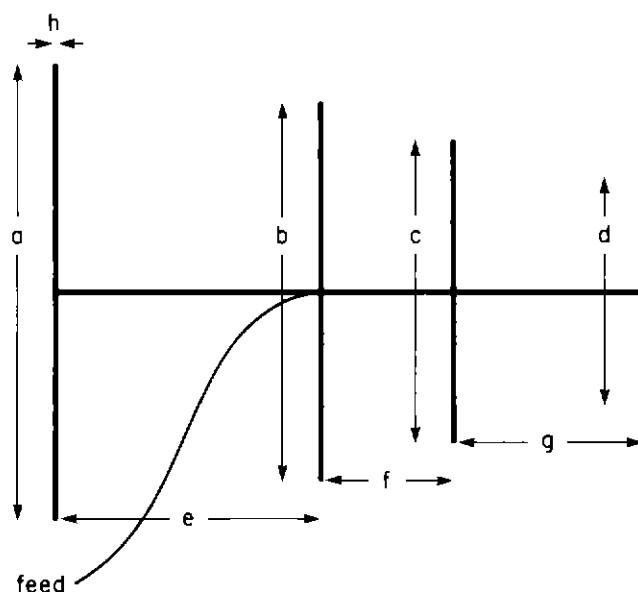


Fig. 1 - Proposed Yagi antenna design.

#### 5. SCALE-MODEL YAGI ANTENNAS

Initially, for ease of measurement, scale models were constructed to check the accuracy of the predicted results; the calculated and measured radiation patterns are given in Appendix 3 and show good agreement.

Models were constructed with either a single dipole and Pawsey-stub balun or with a folded dipole and a trombone balun. These were used to investigate input impedance. Altering the length and spacing of the elements of the model indicated that the radiation patterns were not sensitive to constructional errors. However, the input impedance does change, particularly if the length of the dipole, or the length of the director next to the dipole is not cut accurately, and hence mismatch losses increase.

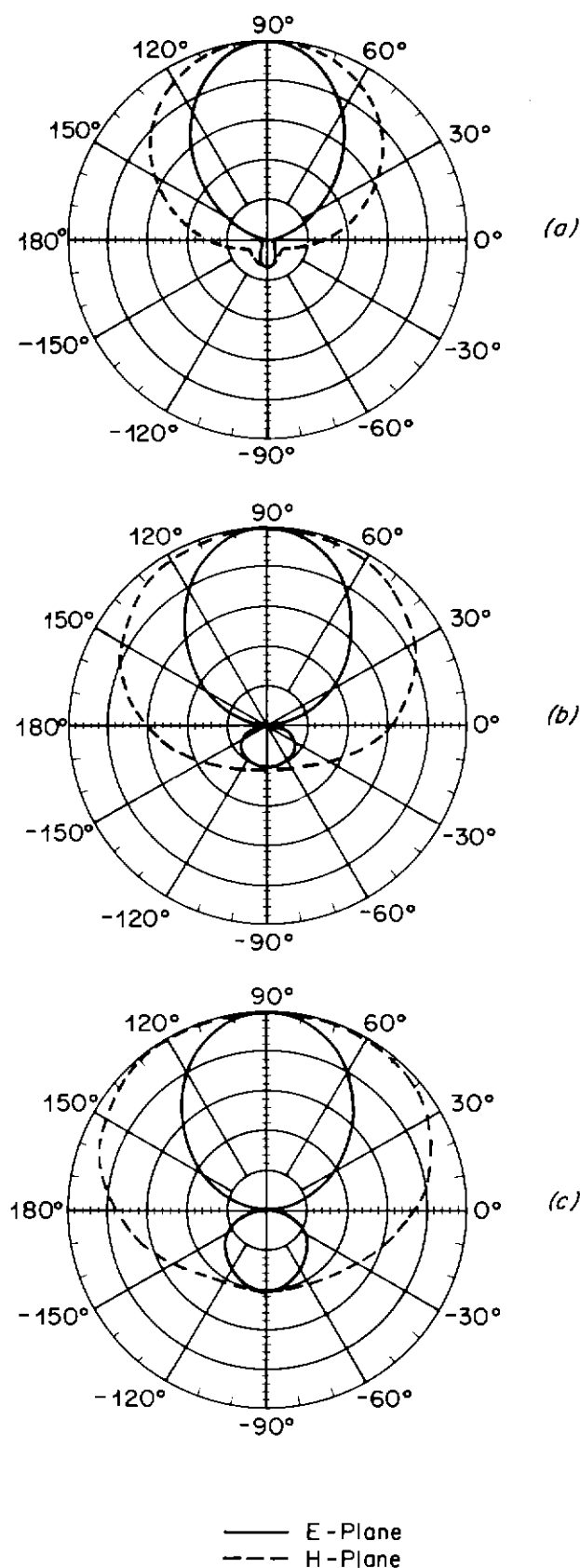


Fig. 2 - HRP's for Yagi antennas:  
 (a) 4 element  
 (b) 3 element  
 (c) 2 element

## 6. FULL-SIZE ANTENNA RESULTS

Two full-size VHF antennas were constructed from aluminium tube. The first was made to the original narrowband Yagi design (see Appendix 1) with a single dipole, rather than a folded dipole, as the driven element. The second was a wideband Yagi antenna constructed according to the dimensions developed using the computer program. As before, a single dipole was used as the driven element making the VHF antenna a full size equivalent to the model described in Appendix 3.

### 6.1 Performance of the original Yagi aerial

HRPs of the original antenna were measured in the required frequency range 88 to 108 MHz. However, this antenna was designed to operate up to 98 MHz and its performance degrades rapidly above this frequency. Fig. 3 shows the measured h.r.p.s within the operating range of the antenna. The gain is fairly high, between 6 and 7.2 dB. By 98 MHz the front-to-back ratio has already decreased to about 9 dB and it decreases further as the frequency increases, until, at 102 MHz, the antenna fires backwards.

The input impedance was measured on a network analyser and the characteristic is shown in Fig. 4. The voltage reflection coefficient lies between 40 - 50% over the 88 to 98 MHz band giving a mismatch loss of 0.8 to 1.2 dB. However, the gain of the antenna is sufficient to accommodate losses of this order and a matching network is not used.

### 6.2 Performance of the new wideband design

The h.r.p. measurements of the new antenna are shown in Fig. 5. As expected, the gain is fairly low, 4.7 to 6.3 dB. The mismatch loss must therefore be kept as low as possible to prevent the gain from being reduced. The cross-polar discrimination of the antenna was measured to be better than 26 dB on boresight.

The input impedance characteristic, without any added compensation, is similar to that of the model, given in Fig. A-3. To improve the match to 75  $\Omega$ , compensation is applied across the drive point. Tapping into a  $\lambda/4$  stub modifies the impedance characteristic, however, the compensating network causes a small shift in the impedance characteristic towards the open circuit end of the plot. To centre the impedance characteristic on 75  $\Omega$ , the transforming effect of the  $\lambda/4$  stub was employed. The feed was connected to the antenna 15 mm nearer the short-circuit than the dipole. The resulting impedance characteristic is shown in Fig. 6.

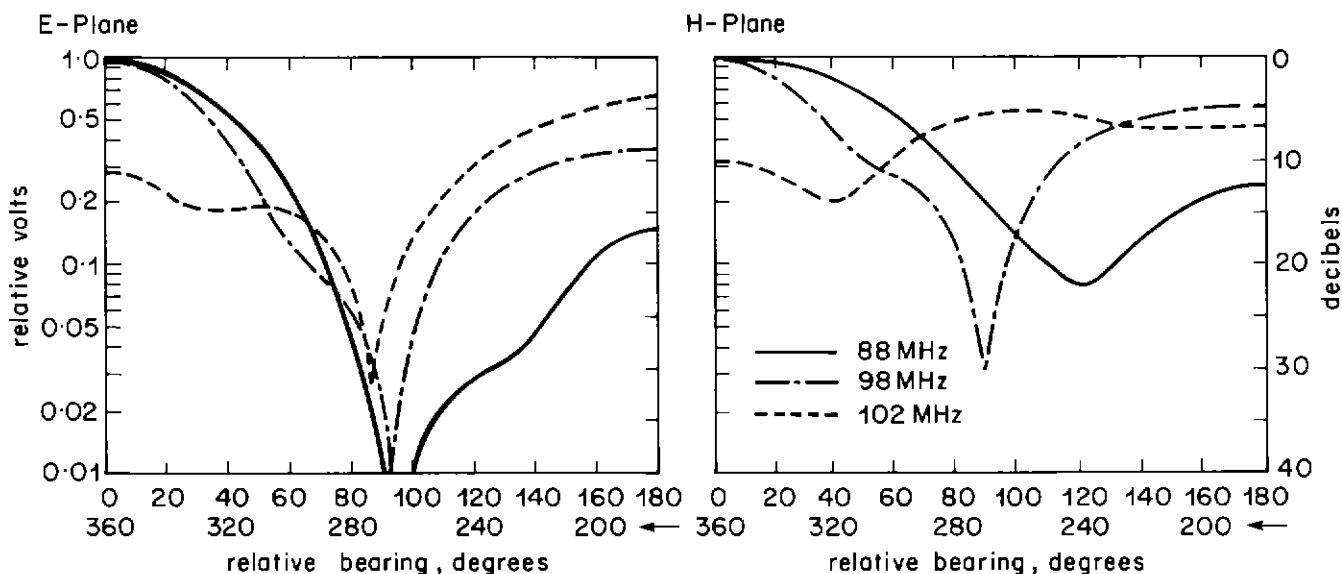


Fig. 3 - HRP's for original antenna design.

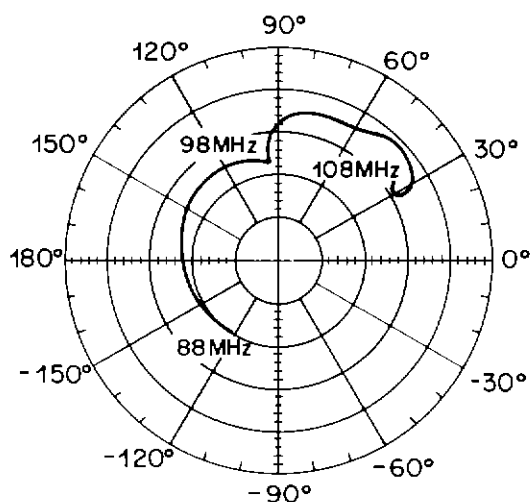


Fig. 4 - Input impedance characteristic for original antenna design (centred on 75 Ω).

The final version of the broadband Yagi antenna is given, with its matching network, in Fig. 7 and its dimensions are given in Table 2.

The dimensions of the compensating stub relate to semi-airspaced domestic UHF cable which has a velocity factor of about 0.77. If a cable is used which has a significantly different velocity factor (i.e. greater than 10%), the length of the cable making up the compensating stub should be changed according to the following equation:-

$$\text{New length} = \frac{\text{old length}}{0.77} \times \text{velocity factor}$$

The velocity factor of antenna cable is usually quoted by the manufacturer.

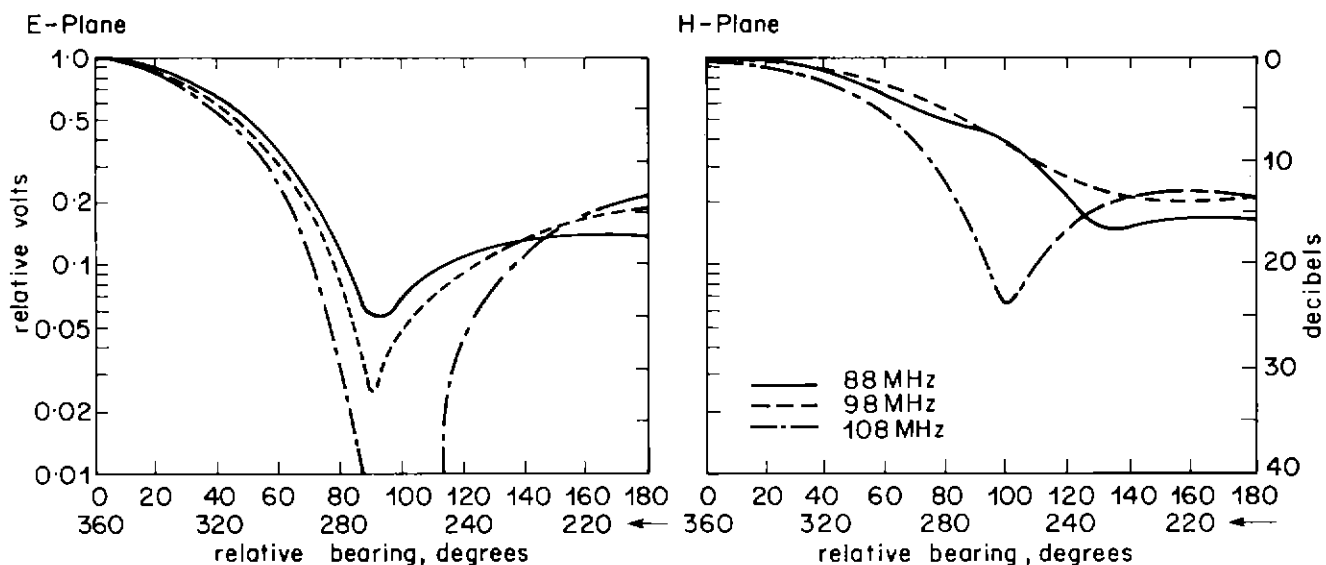


Fig. 5 - HRP's for wideband Yagi antenna.

Table 2 - Dimensions of Full-Size Broadband Yagi Antenna

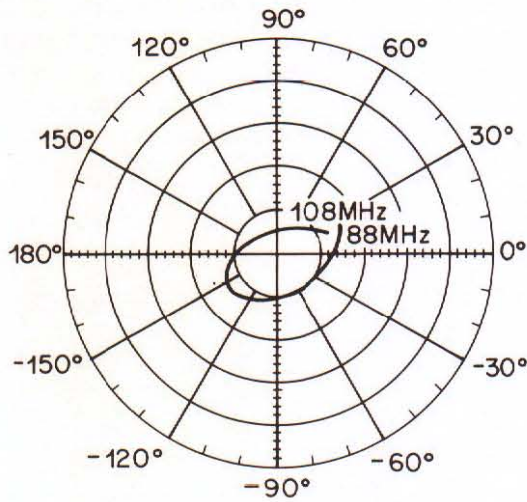


Fig. 6 - Impedance characteristic of a full-size broadband Yagi antenna with impedance transformation.

	Dimension	Length (m)
Element Length	a	1.72
	b	1.5
	c	1.3
	d	1.16
Element Spacing	e	0.77
	f	0.23
	g	0.5
Diameter	h	0.01
Compensating network	i	0.37
	j	0.11
	k	0.015

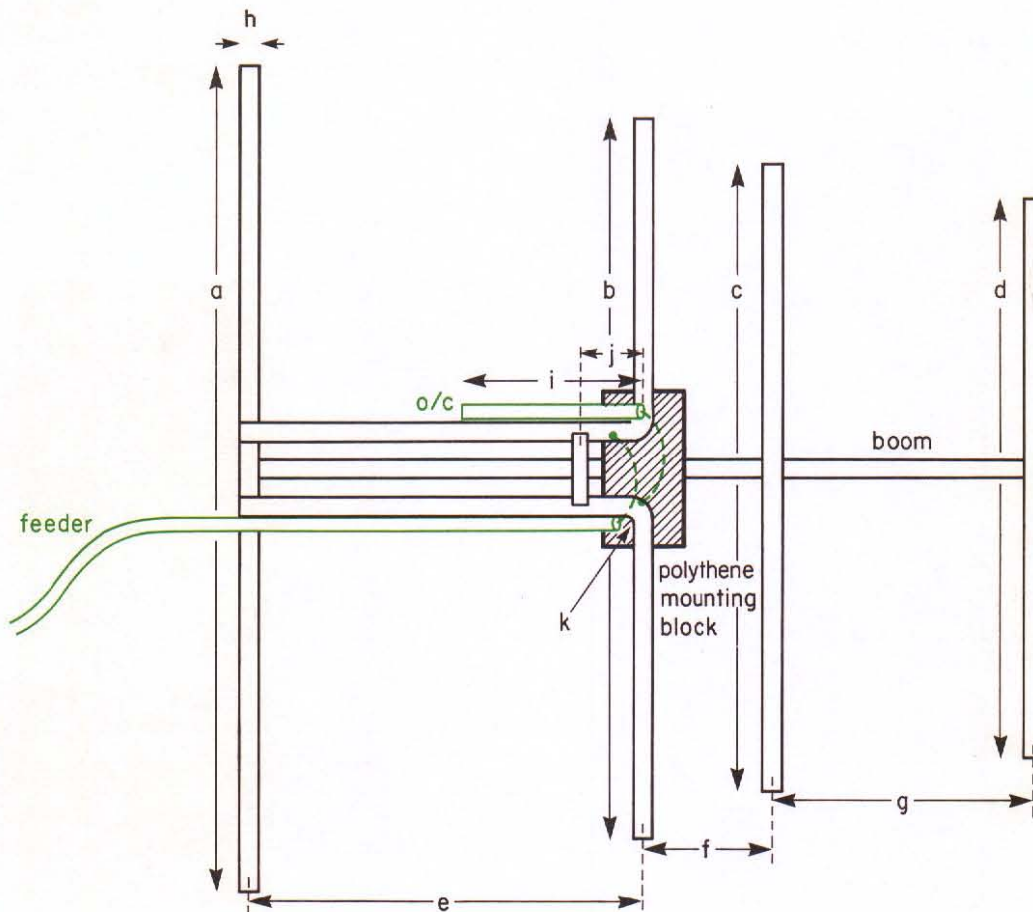


Fig. 7 - Broadband Yagi antenna with matching network.

### 6.3 Construction of the proposed design

The broadband Yagi antenna shown in Fig. 7 was built using 10 mm (3/8") aluminium tube for the elements and 19 mm (3/4") tube for the boom. The elements can be connected to the boom by drilling holes through each element and the boom and bolting them together. This is easier if the sections of tube are flattened slightly first. A piece of polythene was used to mount the dipole onto the boom. A hole drilled through the block of polythene allows it to slide onto the boom.

Holes drilled downwards through the polythene block allow the elements of the dipole to be bolted on together with solder tags for connecting the feed. A photograph of the antenna is shown in Fig. 8(a). Both the feeder and the matching stub are made from lengths of 75  $\Omega$  antenna cable soldered onto solder tags, bolted to the aluminium tube. Fig. 8(b) shows a photograph of the antenna around the feed.

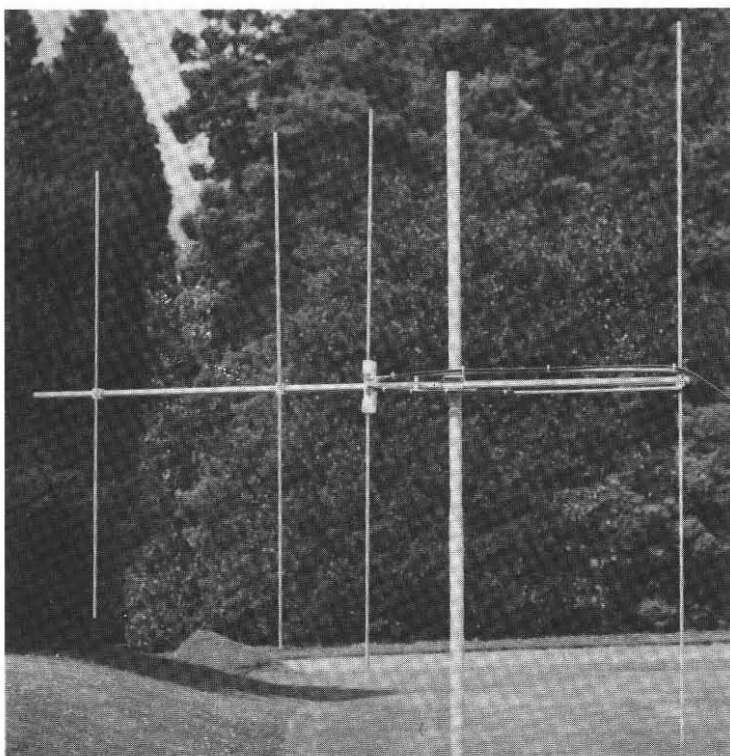
Another version of the antenna was built using standard 15 and 22 mm copper plumbing tubes and fittings. A photograph of the antenna is shown in Fig. 9. This has the advantages that the copper and the feed cable can be soldered which gives a good electrical connection, less likely to suffer from corrosion effects, and the parts are readily available to the home constructor.

The antenna should be clamped with the boom mounted horizontally, pointing towards the transmitter and oriented in the horizontal plane unless the sound transmitter is only radiating vertically-polarised signals. The balun prevents currents flowing in the feed cable from entering the feed point of the antenna. However, any conductor, including the feed cable, near the driven element will have currents induced in it and will re-radiate. Care must therefore be taken when mounting the antenna and routing the feed cable.

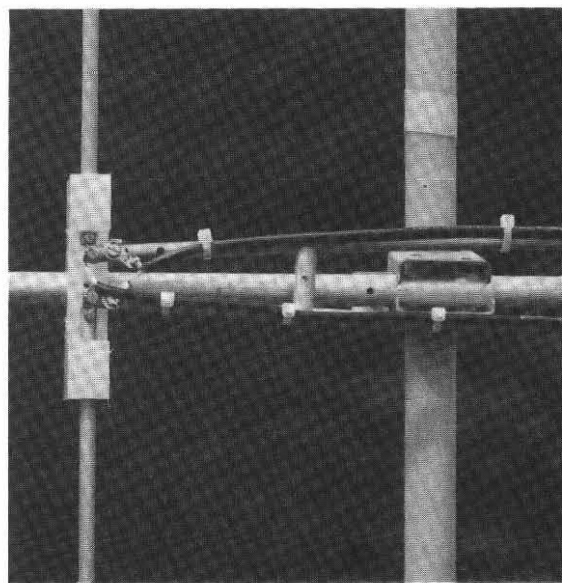
### 7. CCIR RECOMMENDED PATTERNS FOR DOMESTIC VHF RECEIVING ANTENNAS

The CCIR recommends a directivity curve for domestic VHF receiving antennas (Recommendation 599), shown in Appendix 2. Somewhat surprisingly this template applies to both E-plane and H-plane patterns and is intended to be used in transmitter service planning for stereo sound broadcasting. The BBC recommends that stationary VHF receiving antennas be mounted horizontally so their E-plane patterns should comply with the CCIR template.

The proposed broadband Yagi antenna described in this Report was designed with the aim of meeting the stereo directivity characteristic and producing a satisfactory gain. However, it was found impracticable to produce a design meeting this



(a)



(b)

Fig. 8 - Photographs of (a) the full-size VHF Yagi antenna built using aluminium tube and (b) a close-up of the feed arrangement.

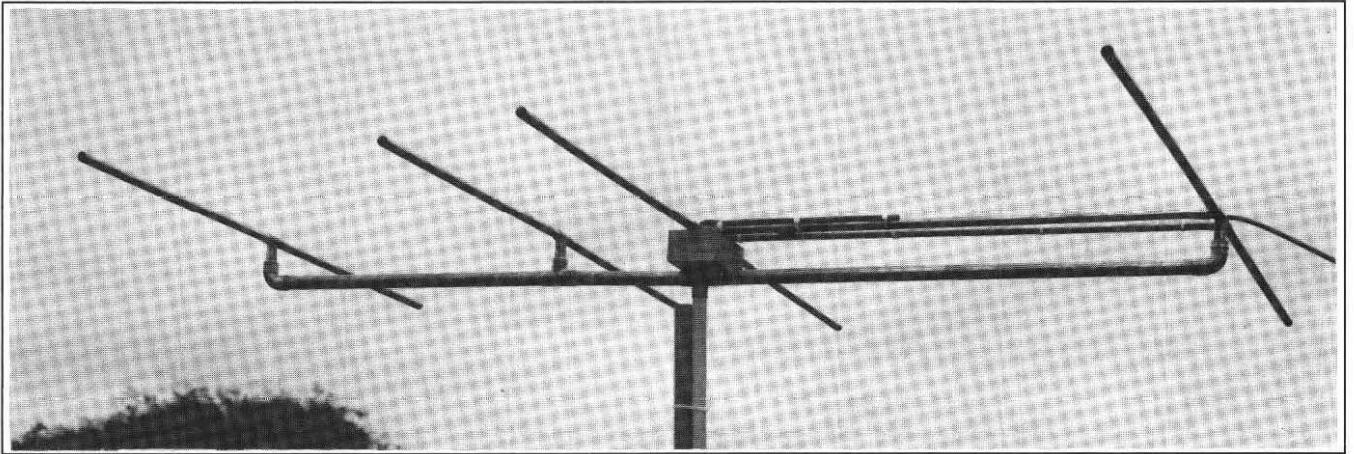


Fig. 9 - Photograph of the full-size VHF Yagi antenna built using copper tube.

criterion over the whole band and on all azimuths. Although the proposed antenna meets the back-to-front ratio required, its main beam is too wide. Fig. 10 indicates the measured performance of the antenna at a clear site. For planning purposes some allowance also has to be made for the apparent loss of directivity under practical conditions as a result of local reflections.

A number of commercially available, VHF receiving antennas with up to 6 elements were measured at the same clear site. They all failed to meet the CCIR template over the full band 88 to 108 MHz but most do comply over a more restricted frequency range. This CCIR planning template is therefore appropriate for the E-plane performance of existing narrowband domestic VHF antennas but the proposed 4-element Yagi antenna will not meet the template for the increased bandwidth, 88 to 108 MHz.

Nevertheless this antenna design is recommended for stereo VHF reception in Band II despite the fact that it does not comply with the CCIR template. Consideration should rather be given to revising the CCIR template to encompass practical antenna designs. The slightly wide main beam suggests that the planning template could be changed so that the linear fall-off meets the  $-12$  dB limit at  $70^\circ$  rather than  $60^\circ$ . A minor change in the planning template will have consequences, but the effects on UK planning will be small. However, the change in template is greater in the H-plane and therefore the consequences may be greater where vertically polarised transmitters are planned.

## 8. DISCUSSION

A four-element Yagi antenna has been developed to operate as a domestic receiving antenna for VHF transmissions between 88 to 108 MHz. The antenna was constructed using a single dipole. A

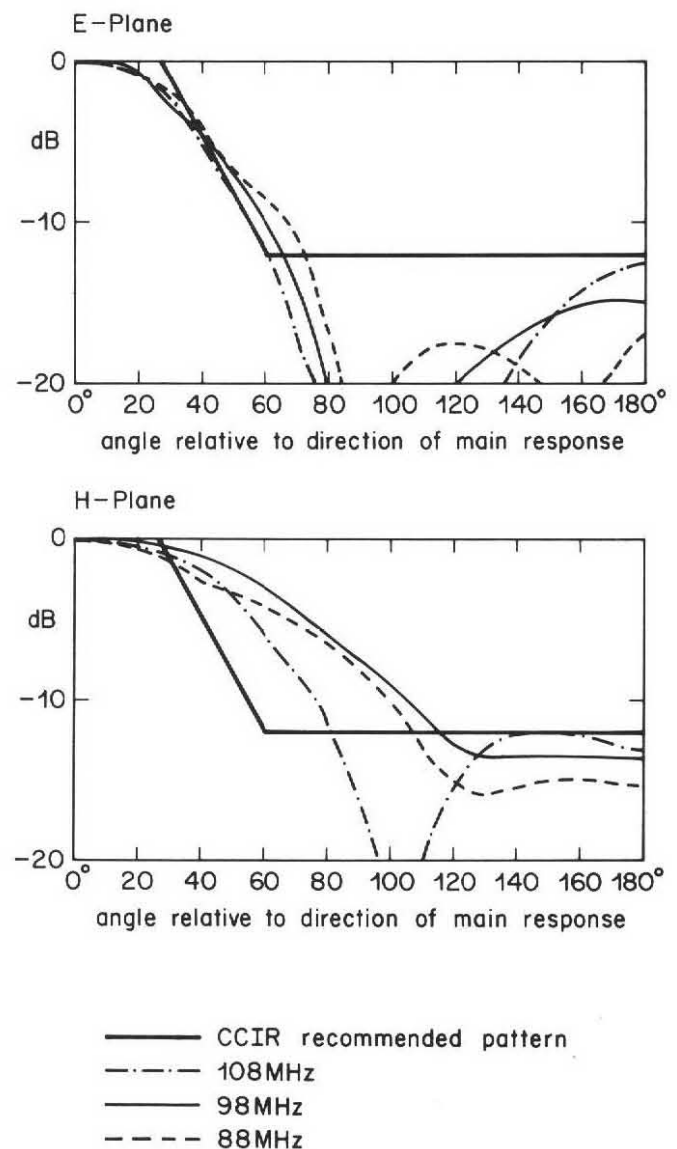


Fig. 10 - Directivity characteristics of proposed broadband Yagi antenna.

folded dipole was not used because it is more difficult to construct and has the same performance as the single-dipole design. The full-size antenna gives an acceptable performance over the required bandwidth, see Table 3.

*Table 3 - Performance of Proposed Wideband Yagi Antenna*

Frequency	88 MHz	98 MHz	108 MHz
Gain	5.3 dB	4.7 dB	6.3 dB
Front-to-back ratio	16 dB	14 dB	13 dB
Mismatch loss	0.4 dB	0.2 dB	0.4 dB

The front-to-back ratio of the antenna is lower than the 20 dB figure aimed for but slightly better than that of the original recommended design. The gain of the broadband antenna is lower than that of the narrowband antenna. However, the new design includes a matching network which gives lower mismatch losses than the old design, so that the overall performance of the proposed broadband design is similar to that of the antenna recommended originally for narrowband use.

The design of a wideband Yagi antenna involves a compromise. In general, increasing the bandwidth reduces the gain. Some of the reduction in gain has been offset by lower mismatch losses, but at the expense of a more complicated feed arrangement. The broadband 4-element Yagi antenna has a fairly wide main beam and so does not conform to the CCIR planning template, but this is not thought to be a significant defect. It may be possible to design a 5-element Yagi antenna which will comply in the

E-plane only but the 4-element antenna cannot meet the template over the whole band.

The antenna can be constructed completely using aluminium or copper tube, 75  $\Omega$  domestic antenna cable and fixings. It is not unduly sensitive to constructional tolerances but the mismatch loss will increase if the two critical element lengths (b and c) are not cut accurately (preferably to within  $\pm 1$  mm).

## 9. CONCLUSIONS

A 4-element Yagi antenna has been developed as a domestic receiving antenna for stereo sound broadcasting in Band II. The antenna has a satisfactory gain and is recommended as a replacement for the original antenna design issued by the BBC's Engineering Information Department for home construction.

The directivity characteristic of the antenna does not comply with the template recommended by the CCIR which is used for planning. It was found impracticable to produce a 4-element Yagi design meeting this directivity criterion over the whole band and on all azimuths. It is recommended that this problem be raised in the CCIR so that the template is reviewed for the E-plane and a separate template is established for the H-plane.

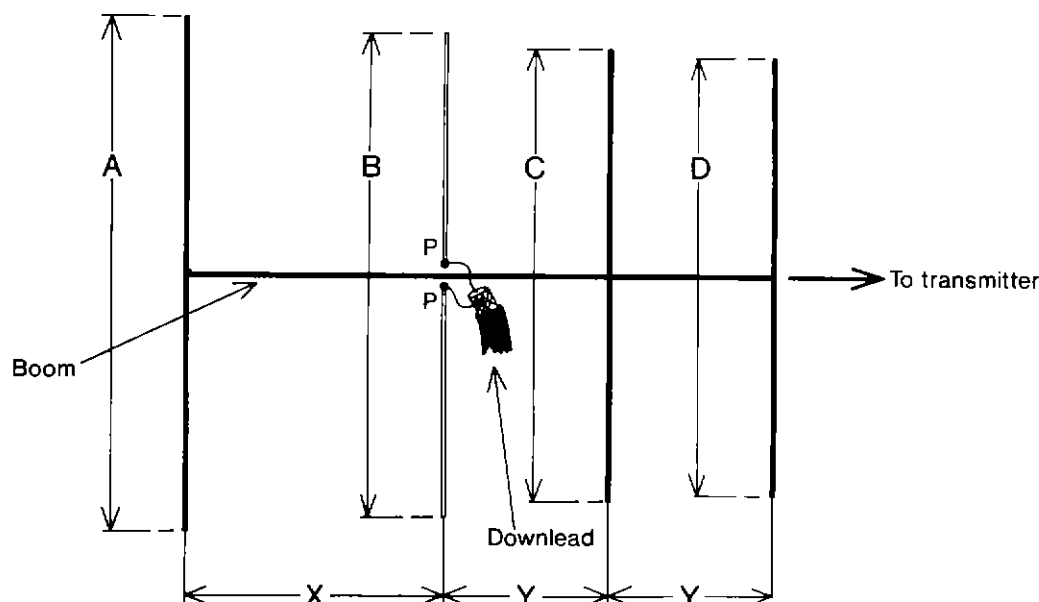
## 10. REFERENCES

1. ITU, 1984. Final Acts of the Regional Administrative Conference for the Planning of VHF Sound Broadcasting, Geneva, 1984.
2. THODAY, R.D.C., 1976. A Wideband Band II Aerial. BBC Research Department Report No. BBC RD 1976/25.
3. JASIK, H., 1961. Antenna Engineering Handbook. New York, McGraw-Hill Book Company, 1961. Section 24.6.

# VHF RADIO RECEIVING AERIALS

## Dimensions for Home Construction

The following notes are intended to assist listeners who wish to construct an aerial for vhf radio reception. The data given below apply to well constructed aerials using good materials, and it must be emphasized that the performance of multi-element aerials depends on accurate alignment of the component elements.



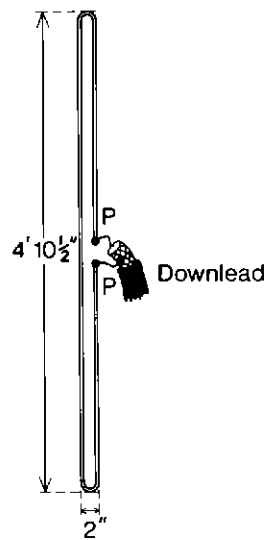
The diagram shows a plan view; the boom and all elements must be arranged in the horizontal plane. If the boom is of metal the feed points P, P, which should be about one inch apart, must be insulated from it. A suitable material for the element is aluminium alloy tube of  $\frac{1}{2}$ " outside diameter. The downlead should be vhf coaxial cable.

The recommended dimensions are as follows (A, B, C and D are for length plus diameter).

A, 5'4"      B, 5'0"      C, 4'9"      D, 4'6"      X, 2'6½"      Y, 1'5"

The aerial can be constructed to the above dimensions to have two (A and B), three (A, B and C) or four elements (A, B, C and D). For monophonic reception, two-element aerials are adequate at most places, whereas for stereophony, three or four elements may be required.

For optimum matching to the downlead in aërials having more than two elements, the dipole (B) should be constructed in folded form, as indicated in the diagram below.



The midpoint of the dipole, opposite to P, P, can be anchored to the boom.

## Appendix 2

### CCIR Recommendation 599

#### DIRECTIVITY OF ANTENNAS FOR THE RECEPTION OF SOUND BROADCASTING IN BAND 8 (VHF)

(Question 46/10, Study Programme 46L/10) (1963-1986)

The CCIR unanimously recommends that the characteristics of directivity of the receiving antennas of Fig. 1 can be used for planning sound broadcasting in band 8 (VHF). However, for portable or mobile reception of sound broadcasts, no directivity of the reception antenna should be applied in planning.

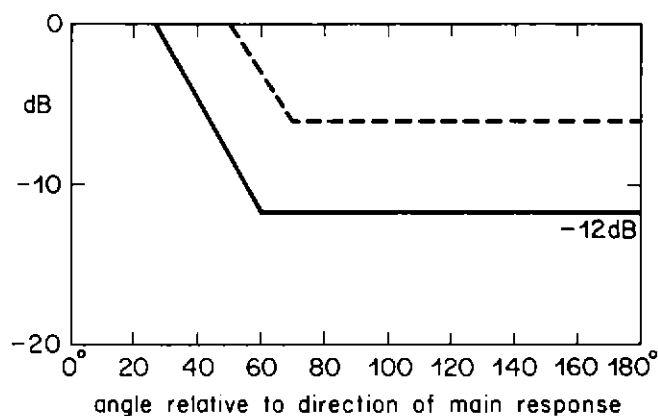


Fig. 1 - Discrimination obtained by use of directional receiving antennas.

--- monophonic-sound broadcasting.  
— stereophonic-sound broadcasting.

Note 1. It is considered that the discrimination shown will be available at the majority of antenna locations in built-up areas. At clear sites in open country, slightly higher values will be obtained.

Note 2. The curves in Fig. 1 are valid for signals of vertical or horizontal polarization, when both the wanted and the unwanted signals have the same polarization.

Note 3. The special Regional Conference, Geneva, 1960, and the European VHF/UHF Broadcasting Conference, Stockholm, 1961, and the African VHF/UHF Broadcasting Conference, Geneva, 1963, did not take the directional characteristics of antennas into consideration for sound broadcasting.

Appendix 2 reproduced with acknowledgement to the CCIR

## Appendix 3

### SCALE-MODEL YAGI ANTENNAS

A scale model of the proposed Yagi antenna design was constructed using a scale factor of 1 : 3.9. Telescopic tube was used to make the antenna and allows the length and spacing of the elements to be altered quickly and easily. The model also allowed the driven element to be changed from a single to a folded dipole. A photograph of the model is shown in Fig. A-1.

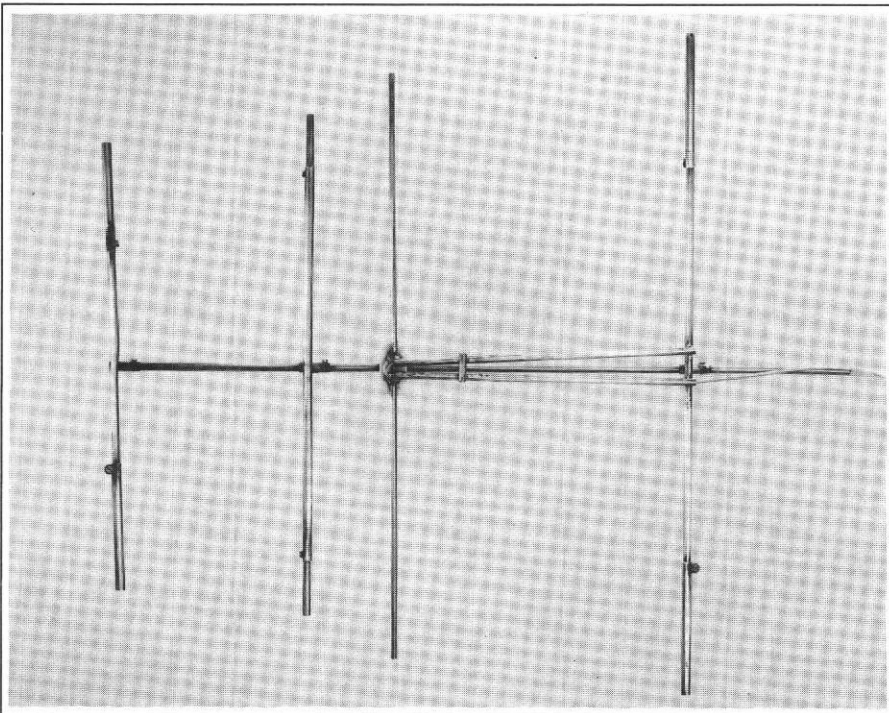
Baluns are used when connecting the feeds to the driven elements of the antennas. This is to prevent any currents induced on the outer braid of the co-axial cable affecting the directional properties of the antenna. If these currents are allowed to enter the feed point they would distort the radiation patterns and would reduce the front-to-back ratio of the antenna.

#### A3.1 Yagi antenna with a single dipole driven element

A model was constructed with a single dipole as the driven element and the element length and spacing taken from Table 1. A Pawsey stub balun was used to connect the feed. This is the arrangement shown in the photograph of Fig. A-1.

The h.r.ps of the antenna were measured across the frequency band and fairly good agreement was obtained between the measured and computed results, see Fig. A-2. The front-to-back ratio is between 14 and 16 dB and the gain rises from 4.3 dB to 5.4 dB between the low frequency and high frequency ends of the band.

The input impedance predicted by the computer program is shown plotted on a Smith chart in Fig. A-3. The measured input impedance is displayed on a network analyser, centred on  $50\ \Omega$  and is also shown in Fig. A-3. For domestic use the antenna should be matched to  $75\ \Omega$  which is marked with a cross (+) on Fig. A-3. The match can be improved by compensating the variation of the impedance with frequency using a matching network. The antenna could be used with the impedance characteristic shown in Fig. A-3 but a mismatch loss of up to 1.2 dB would reduce the overall gain of the antenna.



*Fig. A-1 Photograph of the model Yagi antenna.*

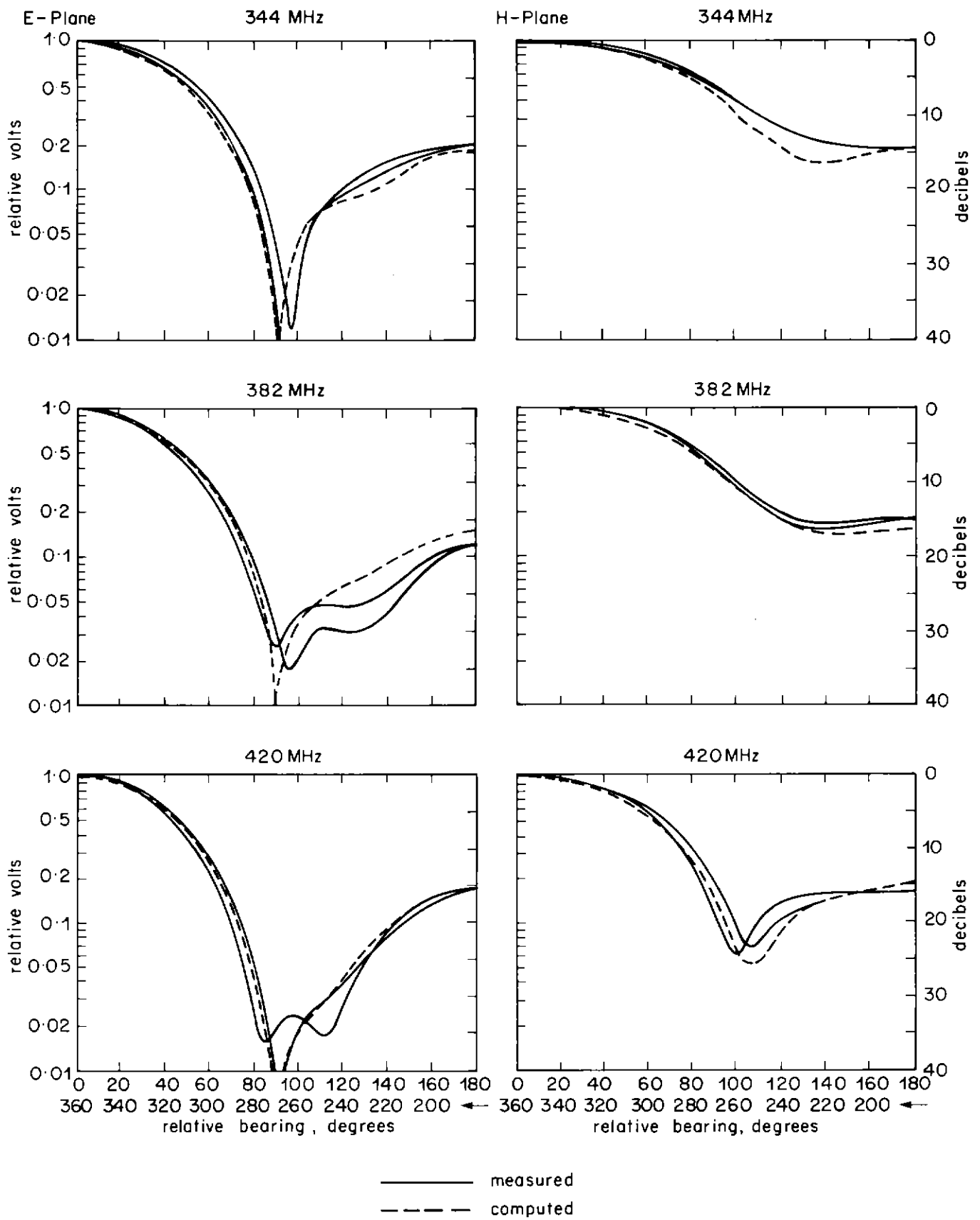


Fig. A-2 HRP's for the model Yagi antenna.

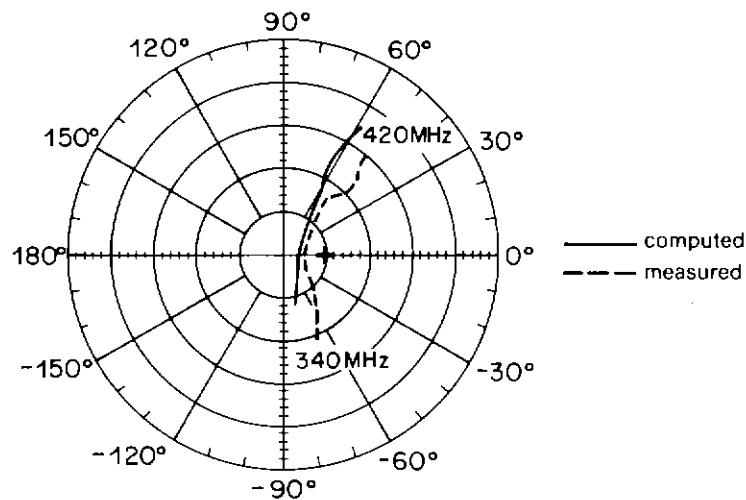


Fig. A-3 Input impedance characteristic for the model Yagi antenna.

The input admittance, derived from the impedance characteristic normalised to  $75 \Omega$ , is plotted as a function of frequency in Fig. A-4. There is a susceptance slope, with the antenna being capacitive at low frequencies and inductive at high frequencies. A compensating network can be connected across the drive point which has a susceptance slope in the opposite direction, that is, capacitive at high frequency and inductive low frequency. This can be achieved by tapping into a  $\lambda/4$  stub, as shown in Fig. A-5. A length of co-axial cable was used to make the stub. The susceptance slope becomes steeper, i.e. more compensation is applied, as the tapping point is moved towards the short-circuit end of the stub. The antenna already has a Pawsey stub balun across the

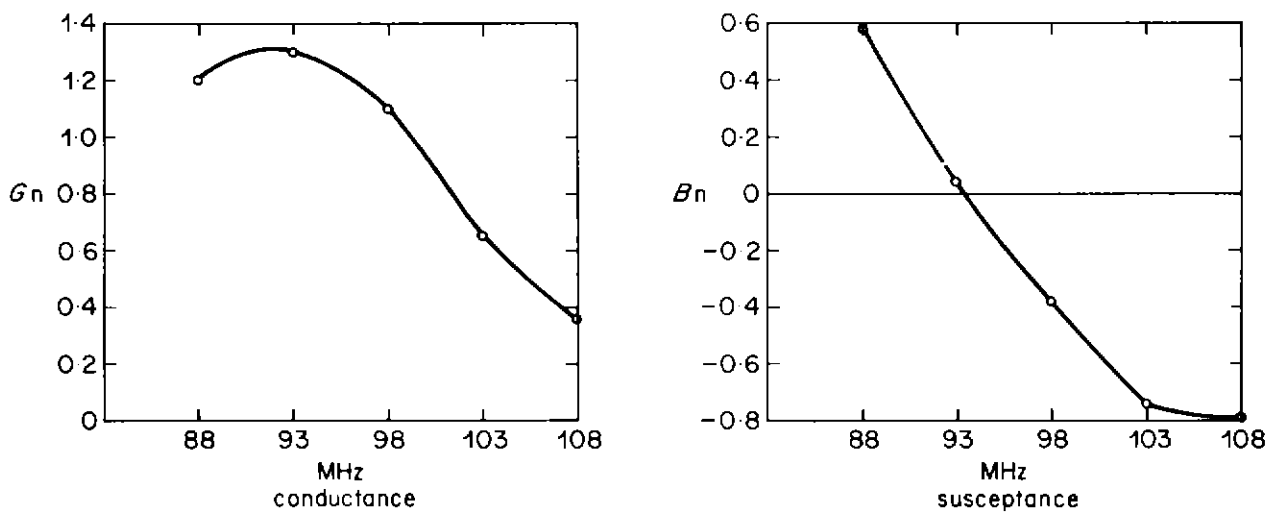


Fig. A-4 Normalised input admittance.

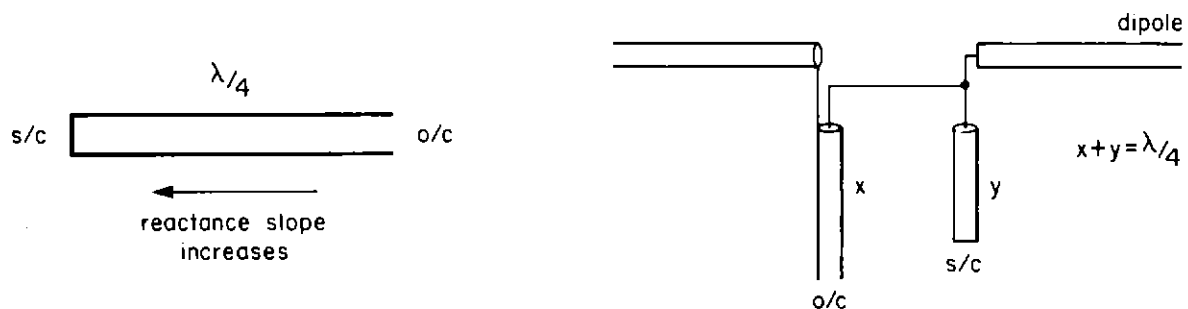
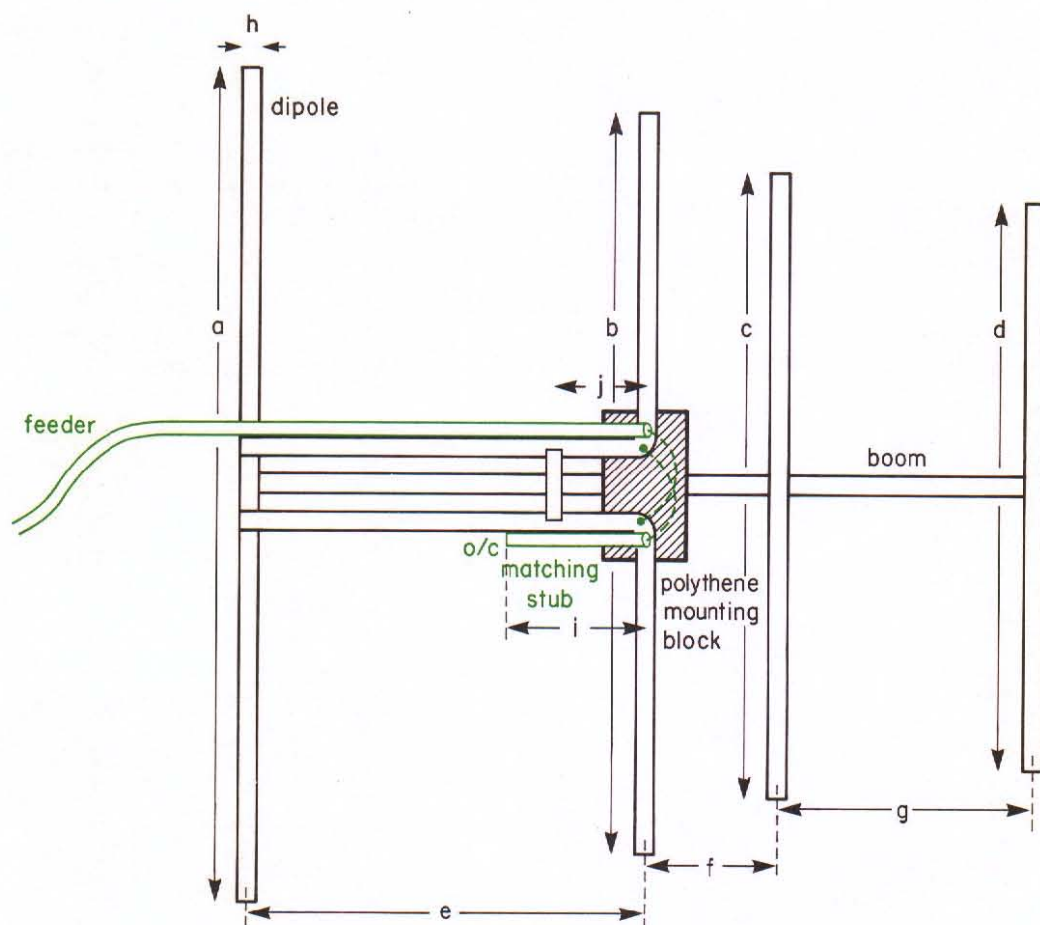


Fig. A-5 Use of a  $\lambda/4$  compensating stub.

drive point, consisting of a balanced two-wire transmission line ending in a short-circuit. It is possible to move the short-circuit along the balun to act as the short-circuit part of the matching network, as shown in Fig. A-6. The final dimensions are given in Table A-1.

*Table A-1: Dimensions of a 1:3.9 model Yagi Antenna with a Single Dipole Driven Element*

	Dimension	Length(m)
Element Length	a	0.438
	b	0.392
	c	0.331
	d	0.295
Element Spacing	e	0.196
	f	0.058
	g	0.127
Diameter	h	0.003
Compensating network	i	0.068
	j	0.045



*Fig. A-6 Yagi antenna with a single dipole driven element and matching network.*

The applied compensation curves the input impedance characteristic around the  $75 \Omega$  point as shown in Fig. A-7. This gives a mismatch loss of only about 0.2 dB.

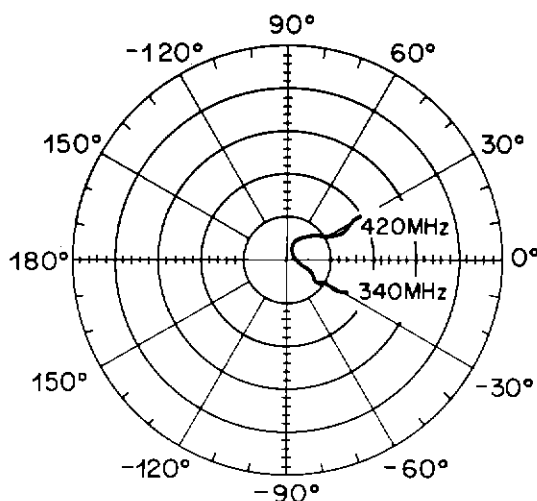


Fig. A-7 Input impedance characteristic for the model antenna with compensation

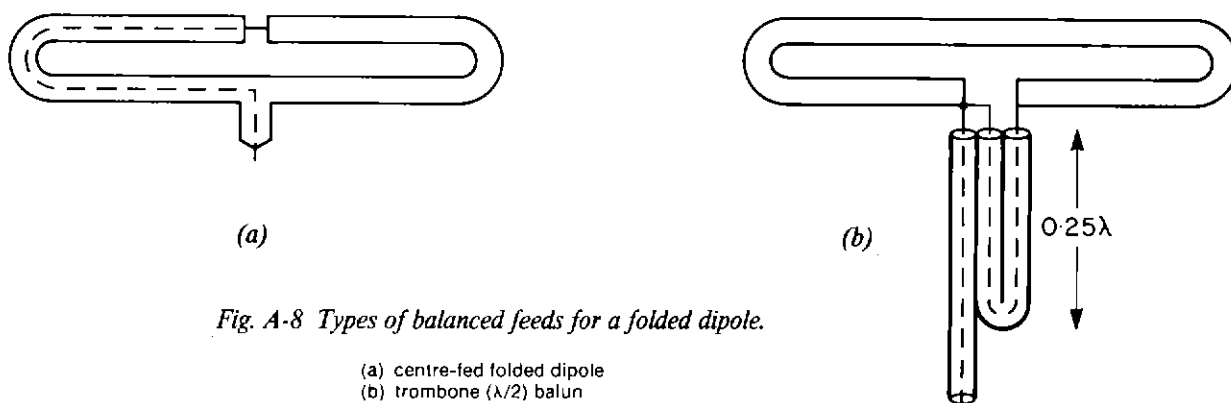
### A3.2 Yagi antenna design with a folded dipole

The use of a folded dipole may improve the impedance match of the antenna. This is suggested for the original antenna design (Appendix 1). There are several ways of providing a balanced feed for a folded dipole. Fig. A-8 shows two methods which are easy to construct.

The centre-fed folded dipole shown in Fig. A-8(a) has the feed co-axial cable connected across the centre of the folded arm. The feed cable is threaded through one half of the folded dipole and the inner is taken across the gap and connected onto the other half. This makes it difficult to mount as the dipole is usually joined to the boom at the centre of the folded arm, where the feed cable enters the dipole.

A trombone balun is shown in Fig. A-8(b). It has an advantage in that it is easily made from a length of feed cable and it allows the dipole to be mounted easily on the boom in the centre of the folded arm. The effect of a half-wavelength section of line across the feed point transforms the input impedance of the antenna.

The folded dipole multiplies the input impedance by 4 and the trombone balun divides it by 4. However, the resulting input impedance is not the same as a single dipole because the folded arm of the dipole does add some compensation.



The input impedance characteristic of the antenna with the balun is inductive and a short open-circuit stub was connected across the feed points to compensate the antenna. The resulting input impedance characteristic is shown in Fig. A-9; the mismatch loss is low, about 0.3 dB.

The final scale-model Yagi antenna design with a folded dipole as the driven element is shown in Fig. A-10. The dimensions of the elements and the feed arrangement are given in Table A-2.

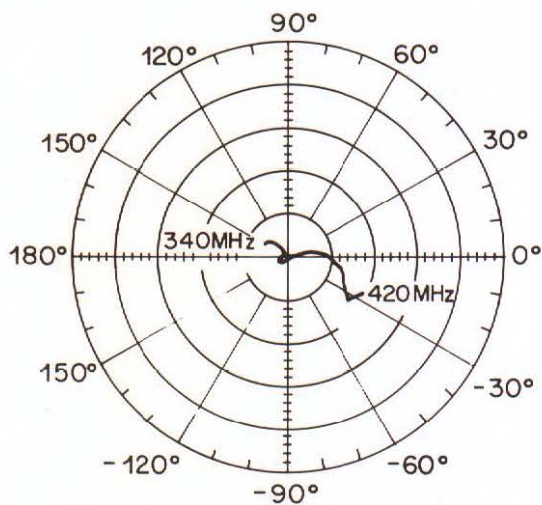


Fig. A-9 Input impedance of a Yagi antenna with a folded dipole.

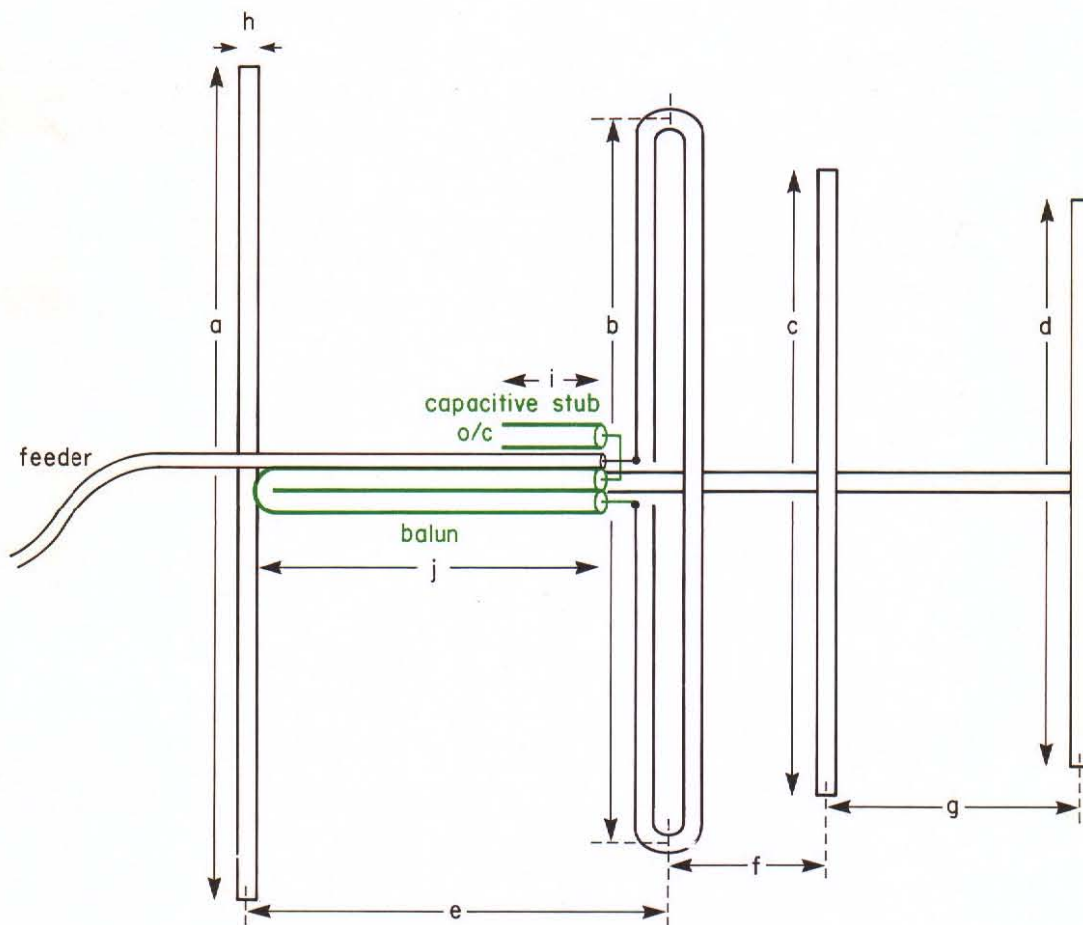


Fig. A-10 Scale model of a Yagi antenna with a folded dipole.

*Table A-2: Dimensions of Model 1:3.9 Yagi Antenna with a Folded Dipole*

	Dimension	Length(m)
Element Length	a	0.438
	b	0.392
	c	0.331
	d	0.295
Element Spacing	e	0.196
	f	0.058
	g	0.127
Diameter	h	0.003
Compensating network	i	0.045
	j	0.274

### **A3.3 Sensitivity to constructional errors**

The flexibility of the scale-model allows the performance of the antenna to be measured with small errors in the length and spacing of the elements. Tolerances of  $\pm 10$  mm for the full-size antenna correspond to errors of the order of  $\pm 2.5$  mm in the model.

HRPs of the antenna were measured with one or more element length or spacing altered by 3 mm. The patterns were compared at three frequencies; at the high frequency and the low frequency ends of the band and at the centre frequency. The small changes in the dimensions had very little effect on the radiation patterns, usually about 1 dB, but up to 2 dB difference in the magnitude of the back lobe.

However, the input impedance is more sensitive to small changes in the length of the elements; in particular, the length of the dipole and the length of the director next to the dipole. Therefore, to keep the mismatch losses as low as possible, the length and spacing of these elements should be accurate to within about  $\pm 1$  mm.